Interim Progress Report on NAG5-356
"Optical Communication
with Semiconductor Laser Diode"

GODDARD
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13P.

F. Davidson and X. Sun

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September 1989

I. Introduction

This interim report describes the progress in the construction of a 220 Mbps Q=4 PPM optical communication system that uses a semiconductor laser as the optical transmitter and an avalanche photodiode (APD) as the photodetector. The transmitter electronics have been completed and contain both GaAs and ECL III IC's. The circuit was able to operate at a source binary data rate from 75 Mbps to 290 Mbps with pulse rise and fall times of 400ps. The pulse shapes of the laser diode and the response from the APD/preamplifier module were also measured.

II. Transmitter Electronics

The design of the transmitter electronic circuit is similar to that of the existing 25 Mbps Q=4 PPM system [1]. A schematic circuit diagram is shown in Figure 1. The circuit was constructed on a prototyping board (GigaBit Logic 90GUPB) with both 10G PICOLOGIC™ GaAs logic circuits [2] and Motorola MECL III logic circuits [3]. The circuit board contained several metal layers which provided various DC power supply voltages to the sites of the IC's. High frequency signals between the IC's were carried by semirigid coax cables (Precision Tubes CE50034). The ECL logic circuits were easy to use but they were not fast enough (~1.3ns rise and fall times) for the part of the circuit that processed the PPM signal and the timing signal. A Q=4 PPM transmitter operating at a binary source data rate of 220Mbps required a slot clock of 440MHz and a PPM pulsewidth of only 2.27ns. GaAs circuits are able to operate at much higher speeds than ECL circuits so they were used where ECL circuits were inappropriate. The transmitter electronics were able to operate with an external slot clock source over a frequency range of 150MHz to 580MHz (75-290Mbps source data rate). The measured pulse rise and fall times were less than 400ps.

The circuit works as follows. The binary data are first stored in a two bit shift register. The two parallel outputs Q0 and Q1 are fed into a 2-to-4 line decoder which translates the two binary bits into a single PPM word in parallel form. The PPM word is loaded into another shift register and then shifted out

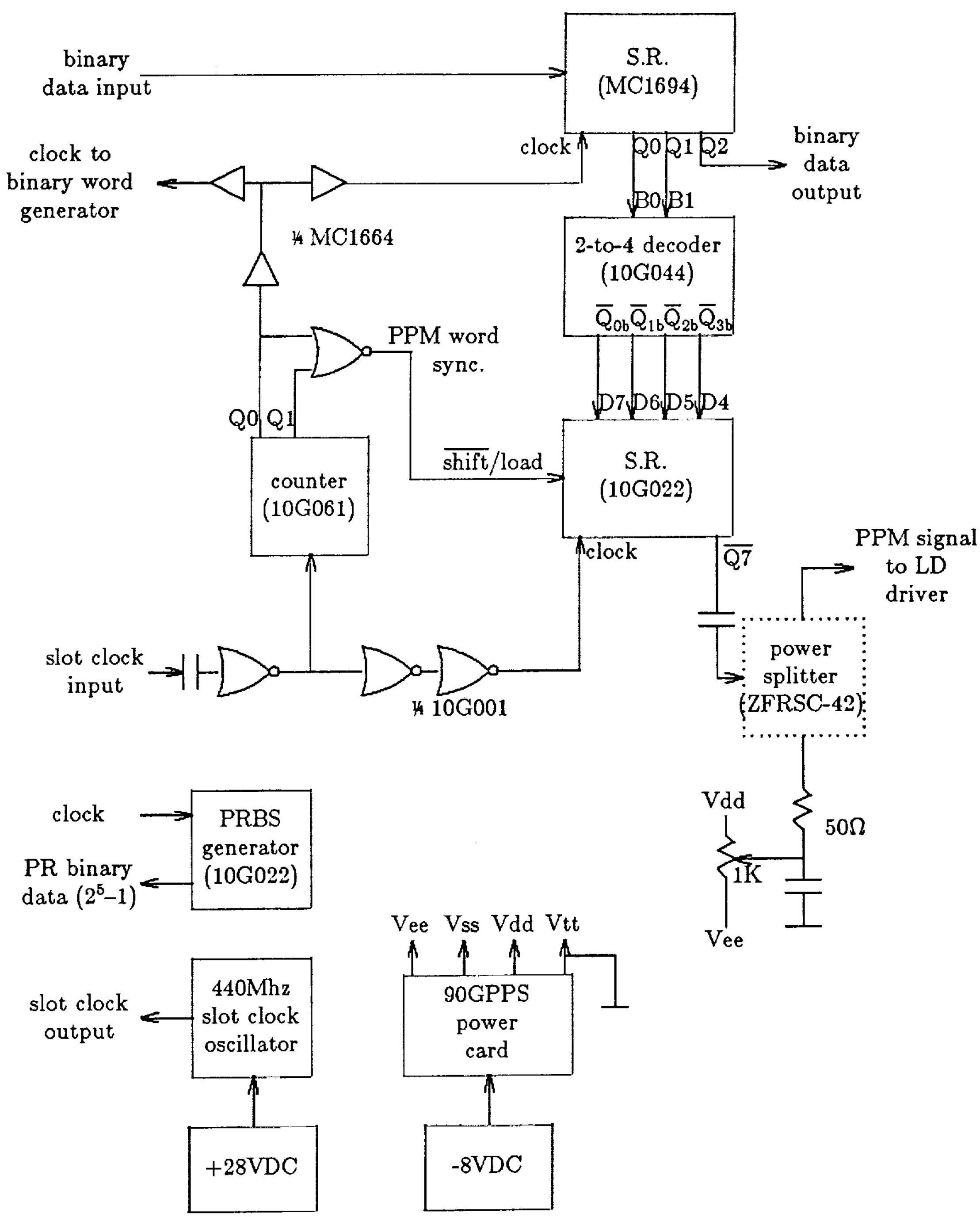

Figure 1. Transmitter circuit diagram

in series. The counter in Figure 1 divides the slot clock by two to generate another clock waveform for the binary data. A NOR gate is used to detect counter state "00" as the PPM word synchronization signal. The correspondence between the PPM word patterns and the two binary bits is shown in Figure 2. The circuit is configured such that the output signals require 50Ω termination to ground (Vtt=gnd) so that they may be directly monitored by an oscilloscope. The only exception is the PPM output signal which is AC coupled. The optional resistive power splitter (Mini-Circuit ZFRSC-42) and the multiturn potentiometer can be used to shift the DC level of the output PPM signal so that it may interface with an ECL level laser diode driver. Since the input threshold level of a laser diode driver is usually fixed, the pulse width of the laser may be adjusted slightly by changing the DC level of the signal. The power splitter also serves as an attenuator which reduces the excessive signal voltage swing between "high" and "low" states output by a GaAs device (V_{OH}–V_{OL}=1.9V) to a standard ECL level voltage swing (V_{OH}–V_{OL}=0.9V).

The transmitter circuit contains a 440MHz crystal oscillator which may be used as a slot clock source. A pseudo random generator (2^5–1=31 bits long, that can be clocked at rates of up to 690Mbps) is also added as an optional binary data source.

III. Measurements of Laser Diode Transmitter Performance

The newly built transmitter electronics circuit was used to test the laser diode to be used in this 220Mbps system. The laser diode (Mitsubishi-ML5702, λ=821nm) and the high speed driver were supplied by NASA Goddard Space Flight Center. The maximum cw output power of the diode was rated as 30mW. The pulse rise and fall times of the laser were about 500ps according to the data supplied by NASA. Measurement data about the spectral purity of the laser was not yet available. The cw output power of the laser diode was first measured as a function of the biasing current at 25°C and zero modulation current setting. As shown in Figure 3, the laser had a threshold current of 50mA and a slope efficiency of 0.42mW/mA.

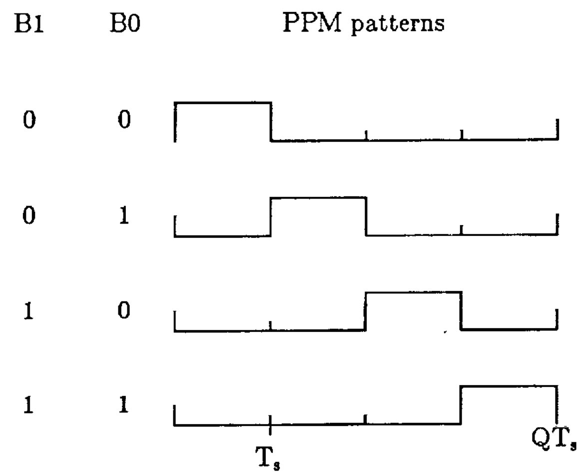

Figure 2. Binary patterns and the corresponding PPM patterns

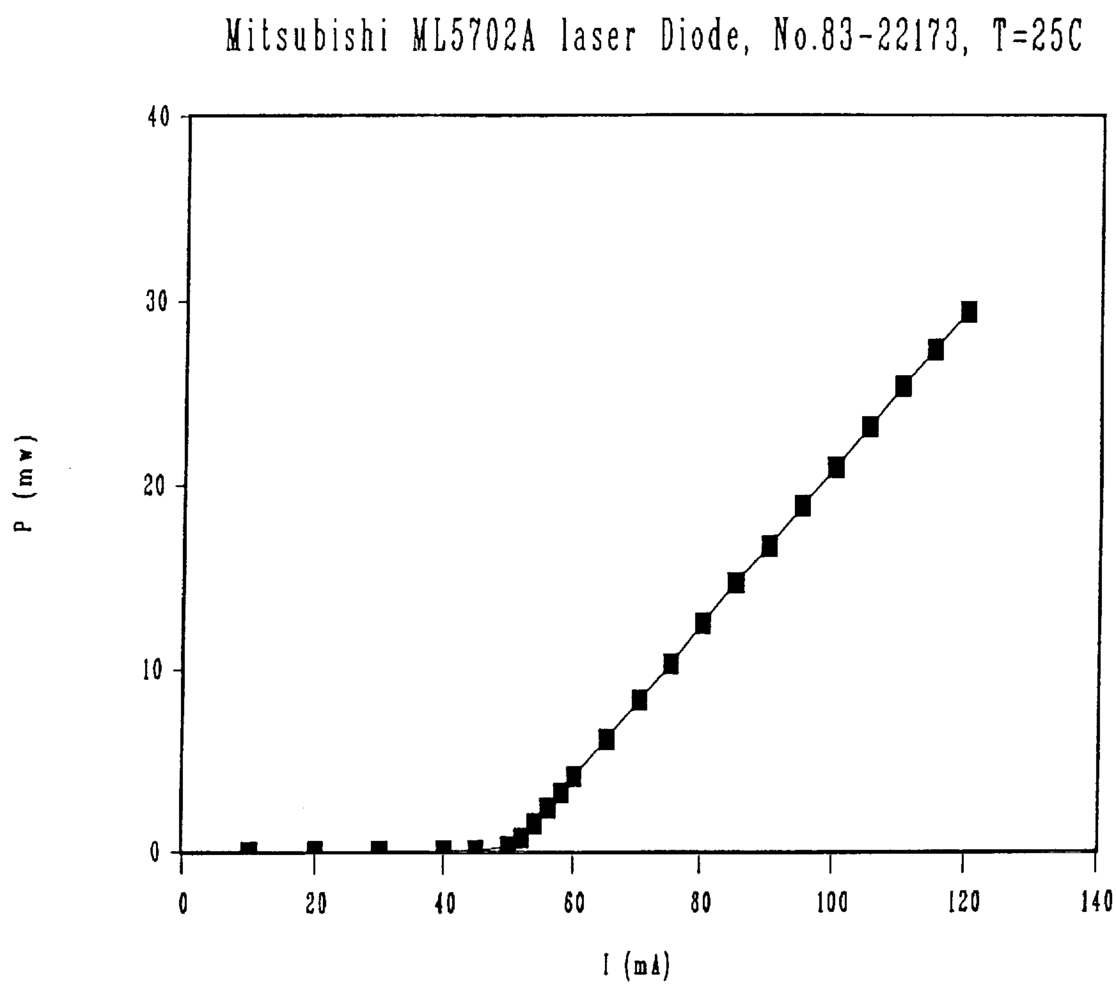

Figure 3. P-I curve of the laser diode

In the presence of nonzero modulation currents, however, the bias current readings from the laser diode driver unit changed. The readings of the modulation current were close to but not exactly equal to values of the actual modulation current to the laser diode. This was verified by biasing the laser well above its threshold current and measuring the difference in the average output optical powers in the presence and absence of a modulation signal. Ideally, the increase in the measured optical power should be equal to the product of the modulation current, the slope efficiency, and the duty cycle of the modulating signal waveform. The readings given by the driver unit could only be used as a relative reference. The actual peak power of the laser diode and the ON-OFF extinction ratio had to be determined through direct measurements.

The waveform of the PPM signal output from the transmitter circuit is shown in Figure 4. The upper graticule contains the waveform of the pseudo random binary sequency (top trace) and the corresponding PPM signal input to the laser diode driver (lower trace). The trace in the lower graticule is the magnified PPM signal waveform. As shown in Figure 4, the electrical pulses used to drive the laser diode had rise and fall times of less than 400ps.

The laser output optical pulse shape was measured by a high speed APD (Newport 877) followed by a wideband amplifier (Avantek AV-9T, 17dB gain over 100Hz-500MHz). Figure 5 shows the measured waveform when the laser was biased below the threshold level. The measured average optical powers when the modulation was ON and OFF were 3.7mW and 0.1mW (the driver unit read I_{bias}=85mA, I_{mod}=50mA). The 0.1mW measured power when the modulation was OFF corresponded mainly to the broadband spontaneous emission. The optical power within the receiver bandwidth (~5nm) should be much smaller and, consequently, the actual ON-OFF extinction ratio seen by the photodetector should be very large. The rise and fall times of the waveform shown in Figure 5 were limited by the amplifier following the APD rather than the laser diode itself. This was verified by feeding the electrical driving pulses directly to the amplifier and measuring the output pulse shape.

The optical output waveform when the laser diode was biased above its threshold current was very similar to that shown in Figure 5. However, when

Figure 4. Transmitter circuit outputs. The top trace in the upper graticule shows the 31 bit long pseudo random source binary sequence. The lower trace in the upper graticule shows the corresponding PPM waveform. The trace in the lower graticule shows the magnified PPM waveform. The two vertical lines define the region where measurements of the pulse rise time, fall time, and pulsewidth were performed. The four horizontal lines indicate the 0%, 20%, 80% and 100% of the pulse amplitude, respectively.

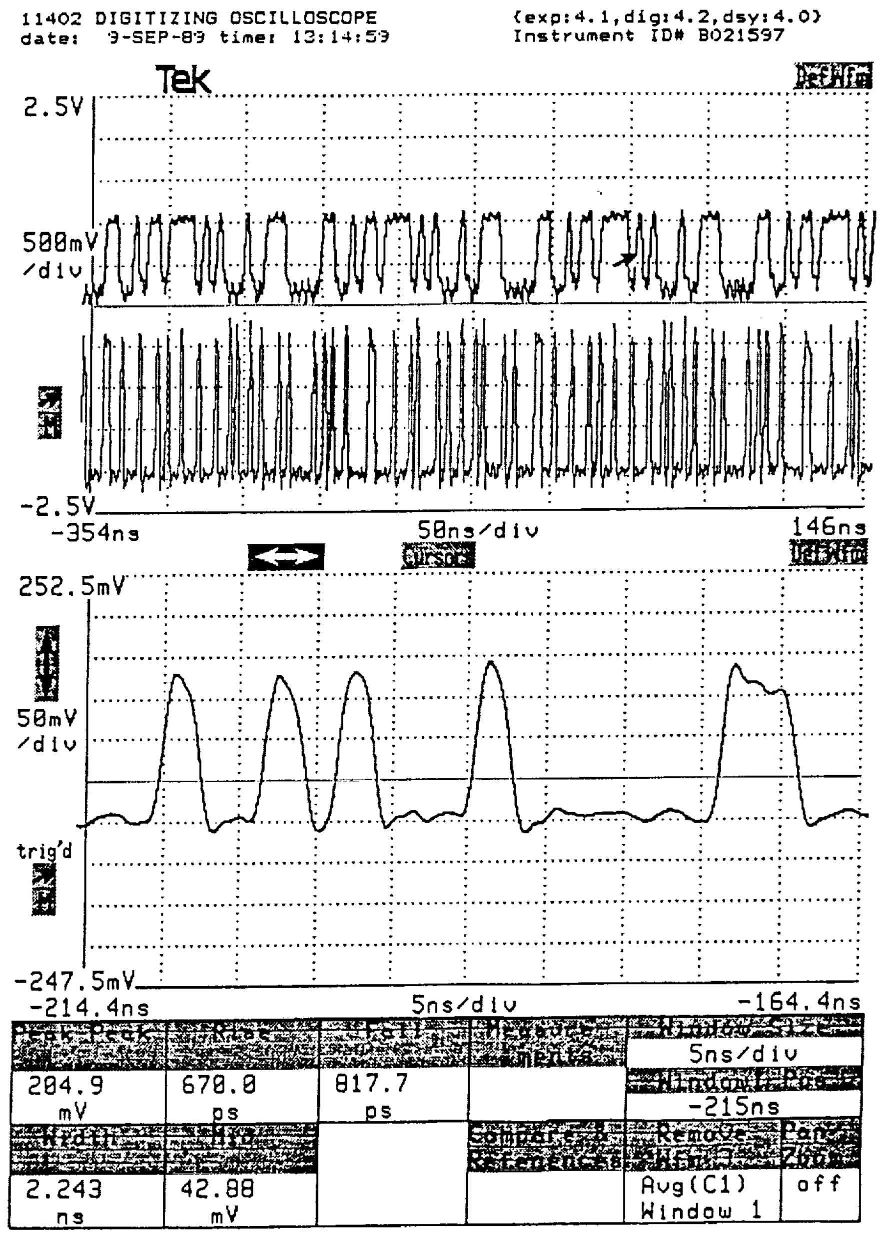

Figure 5. Output pulse shapes from the laser diode when modulated by the PPM signal and biased below its threshold level.

the bias level was too low, for example, I_{bias}=50mA (as read from the driver unit), the laser pulse shape might be severely distorted, especially for a random modulation signal waveform.

The APD (RCA-30902S) and preamplifier assembly which are considered as a candidate photodetector for this 220Mbps system was also tested. Figure 6 shows the measured output waveform from the preamplifier. A magnified and averaged waveform is shown in the lower graticule. The pulse amplitude fluctuation shown in the upper graticule was caused by the randomness of the APD gain. It was found from Figure 6 that the APD preamplifier bandwidth caused significant ringing in the detected PPM waveform. This may cause significant intersymbol interference in the receiver. The APD gain was measured to be G=300 which was close to the optimal value predicted by numerical computations.

IV. Conclusions and Future Work

The transmitter electronics have been completed and successfully tested with Q=4 PPM signaling at a source data rate of 220Mbps. The APD/preamplifier assembly was shown to work but cause ringing in the detected PPM waveform.

The next phase of our work consists of following. (1) An APD preamplifier with wider bandwidth will be sought which can give a near rectangular output pulse shape with little ringing. (2) A special matched filter will be designed for the resultant pulse shape. (3) Spectral properities of the laser diode will be studied in order to determine the center wavelength and the bandwidth of the interference optical filter preceding the APD photodetector. (4) The receiver electronics will be completed. (5) The entire system will tested and the performance will be measured.

References

[1] X. Sun, *Free-Space Direct-Detection Optical Communication with Semiconductor Laser Transmitters and Avalanche Photodiode Photodetectors,* Ph.D

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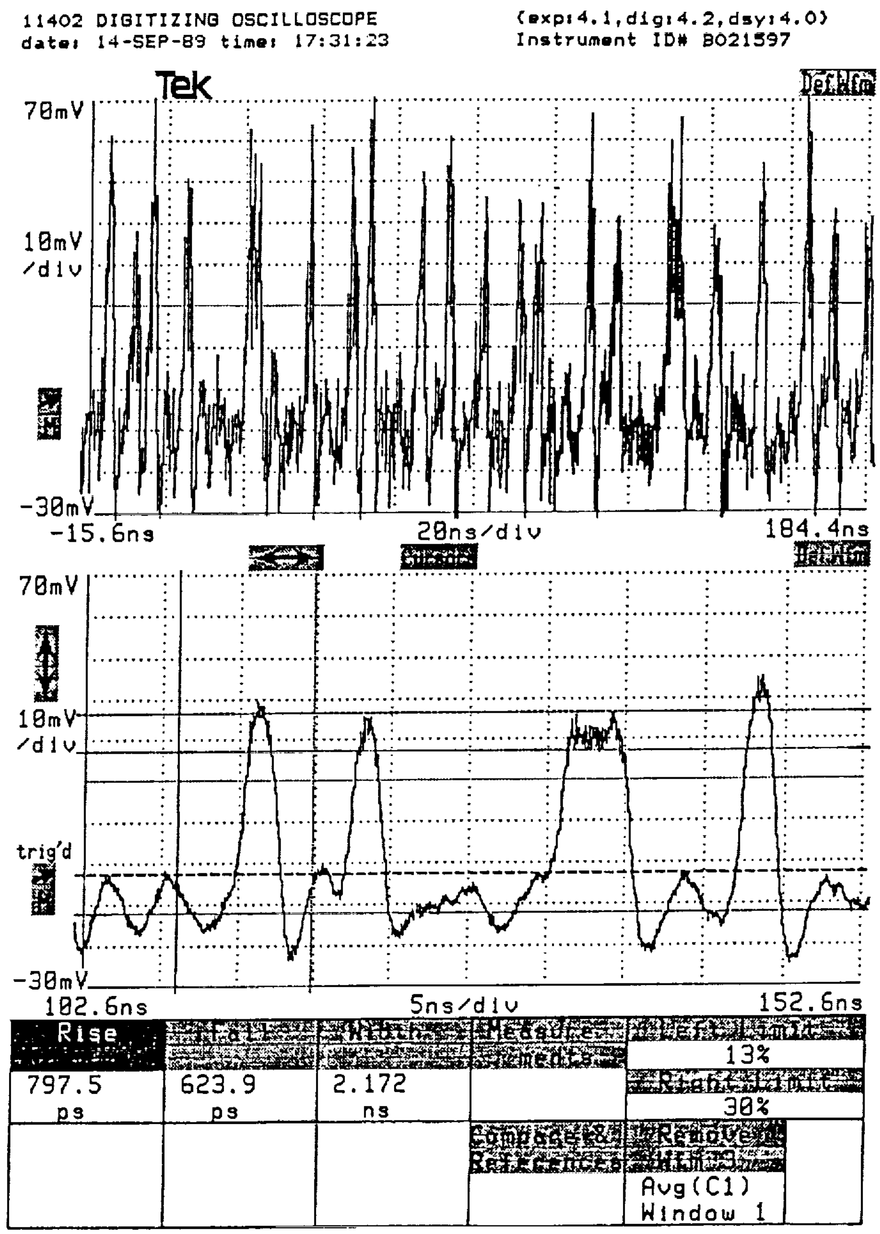

Figure 6. Detected PPM waveform output by the APD preamplifier. The lower graticule shows the magnified and averaged waveform.

Thesis, the Johns Hopkins University, 1989.

[2] *MECL Device Data,* Motorola Inc., 1987.

[3] *GaAs IC Data Book & Designer's Guide,* GigaBit Logic Inc., 1988.